

## **Basalt fibres for concrete strengthening**

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# Basalt Fibres for concrete strengthening

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Work carried out at The University of Sheffield  
Prof. K. Pilakoutas  
Dr M. Guadagnini



- Research Rationale
- Experimental work
- Findings and Conclusions

- **Traditional - Steel**



*G. Nichols*



- **Modern - Fibre Reinforced Polymers (FRPs)**



Carbon, Glass, Aramid



*sika.com*



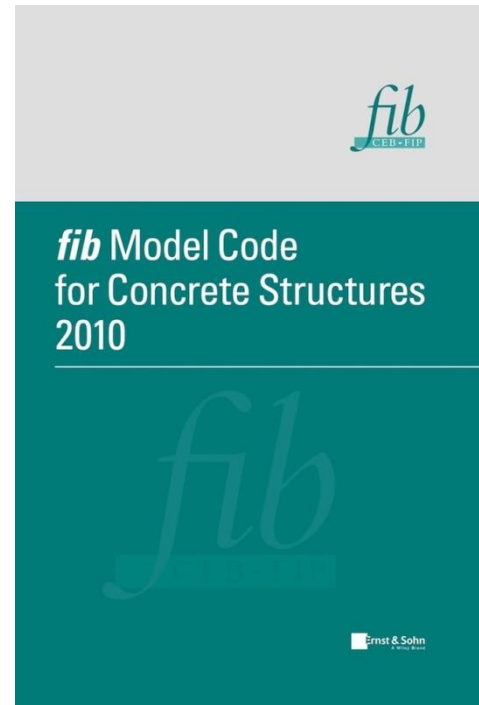
*buildera.com*

# FRPs for Strengthening of Concrete

2<sup>nd</sup> International Workshop

20-24 November 2017, Istanbul, Turkey

FRP as reinforcement for concrete has already been validated!



DESIGN MANUAL FOR ROADS AND BRIDGES

BD 85/08  
Volume 1, Section 3,  
Part 18



THE HIGHWAYS AGENCY



SCOTTISH GOVERNMENT



WELSH ASSEMBLY GOVERNMENT  
LLYWODRAETH CYNULLIAD CYMRU



THE DEPARTMENT FOR REGIONAL DEVELOPMENT  
NORTHERN IRELAND

## Strengthening Highway Structures Using Externally Bonded Fibre Reinforced Polymer

**Summary:** This Standard covers the strengthening of concrete and metallic highway bridges, on trunk roads including motorways, using externally bonded fibre reinforced polymer (FRP). This Standard does not cover the use of prestressed plates or other systems in which the FRP is subjected to sustained long-term loading. This Standard does not cover the strengthening of prestressed concrete structures, although many of the issues and limit states described will also be relevant to the design of FRP strengthening schemes for such structures. Design guidelines are provided for flexural and shear strengthening of reinforced concrete bridge decks. Design guidelines for strengthening metallic bridge decks are limited to flexural strengthening. In addition, general guidance is provided on suitable strengthening techniques.

- Cost Issue

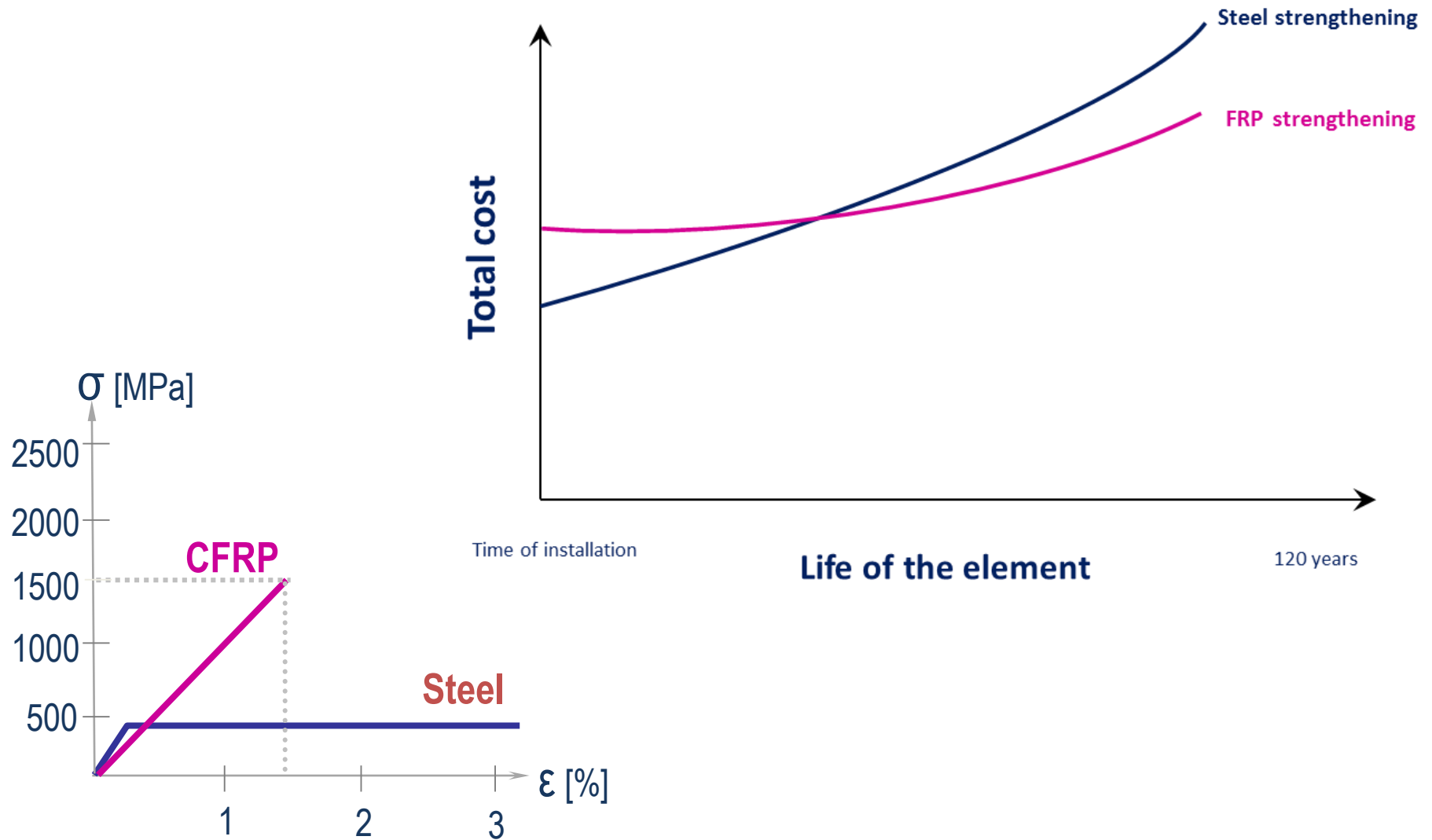


- Debonding Issue

# FRP Cost Issue

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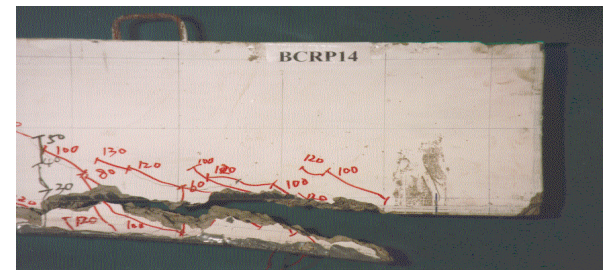
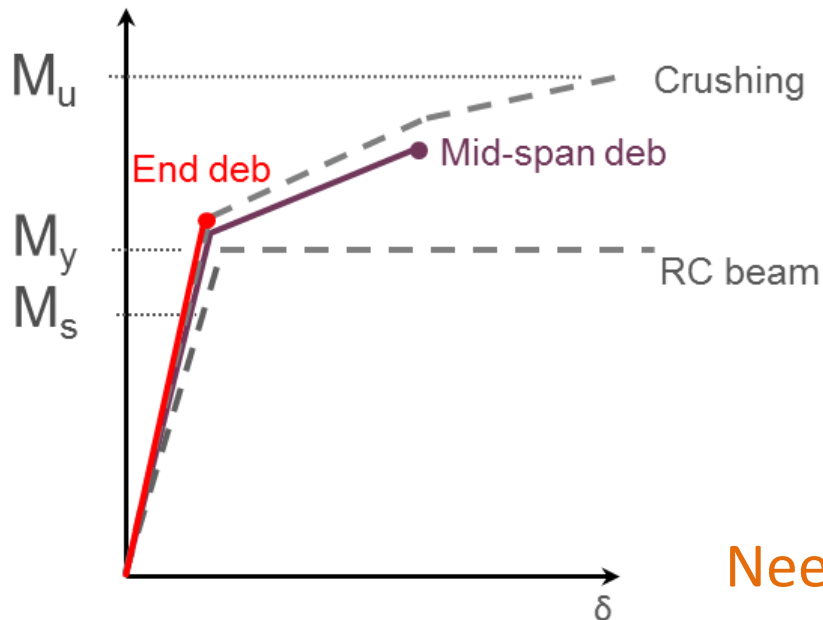
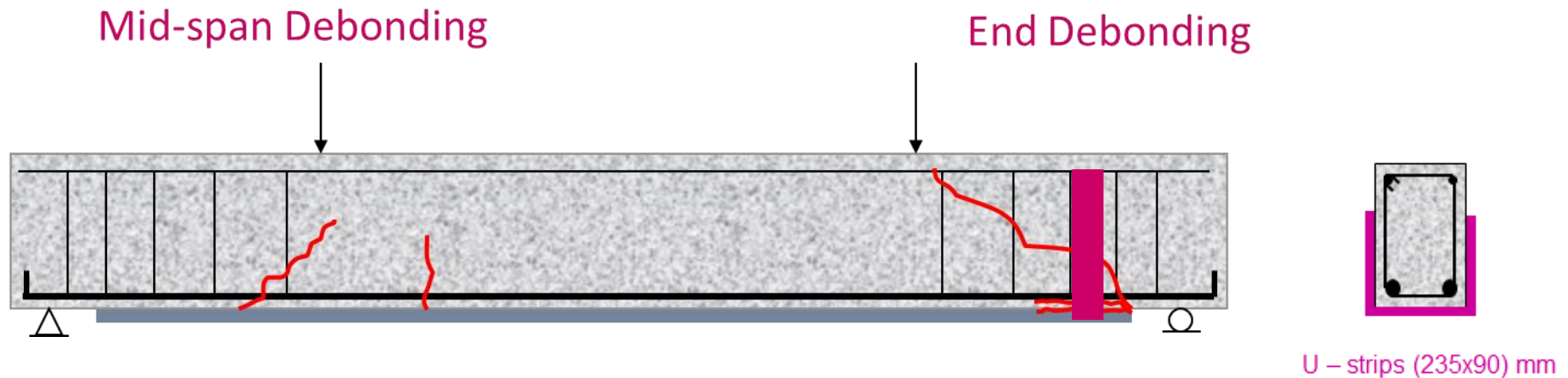




# FRP Debonding Issue

2<sup>nd</sup> International Workshop

20-24 November 2017, Istanbul, Turkey



Need for a more cost effective fibre!

# Relatively new Basalt Fibers

2<sup>nd</sup> International Workshop

20-24 November 2017, Istanbul, Turkey



Volcano



Basalt Rock



Basalt Plant



Basalt Fibres



Furnace



Crushed Basalt Rock

Basalt fabric



Basalt FRP (BFRP)  
bars/plates/strips

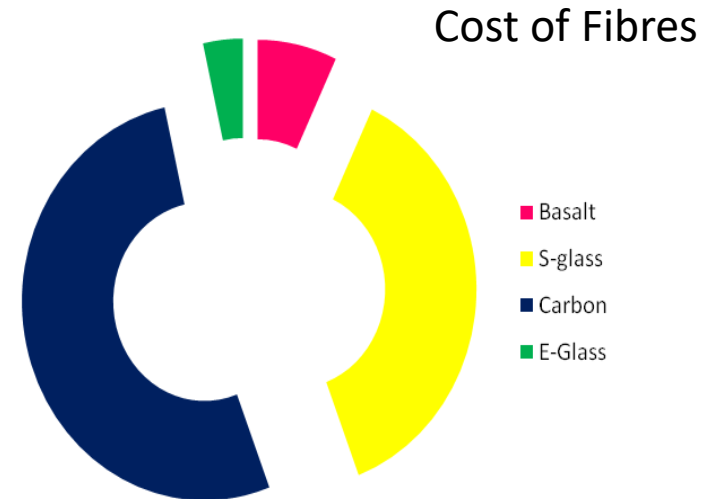
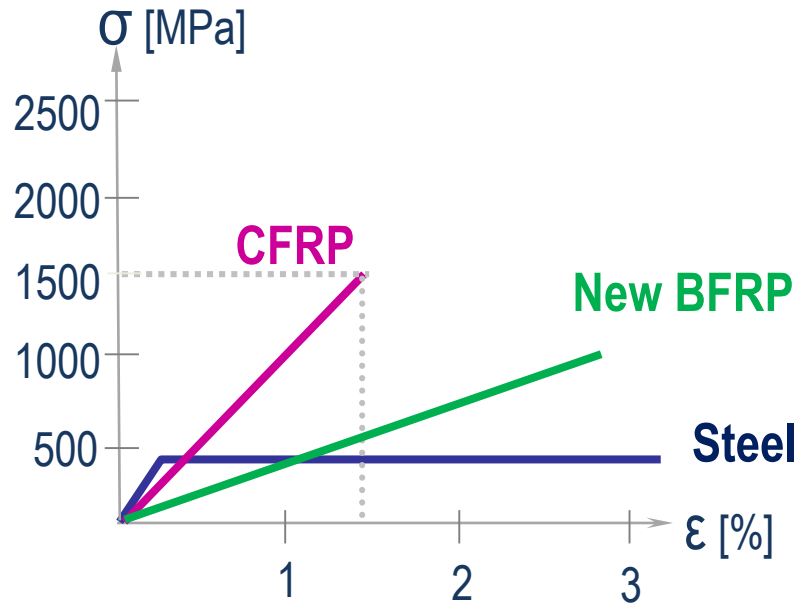




# Relatively new Basalt Fibers

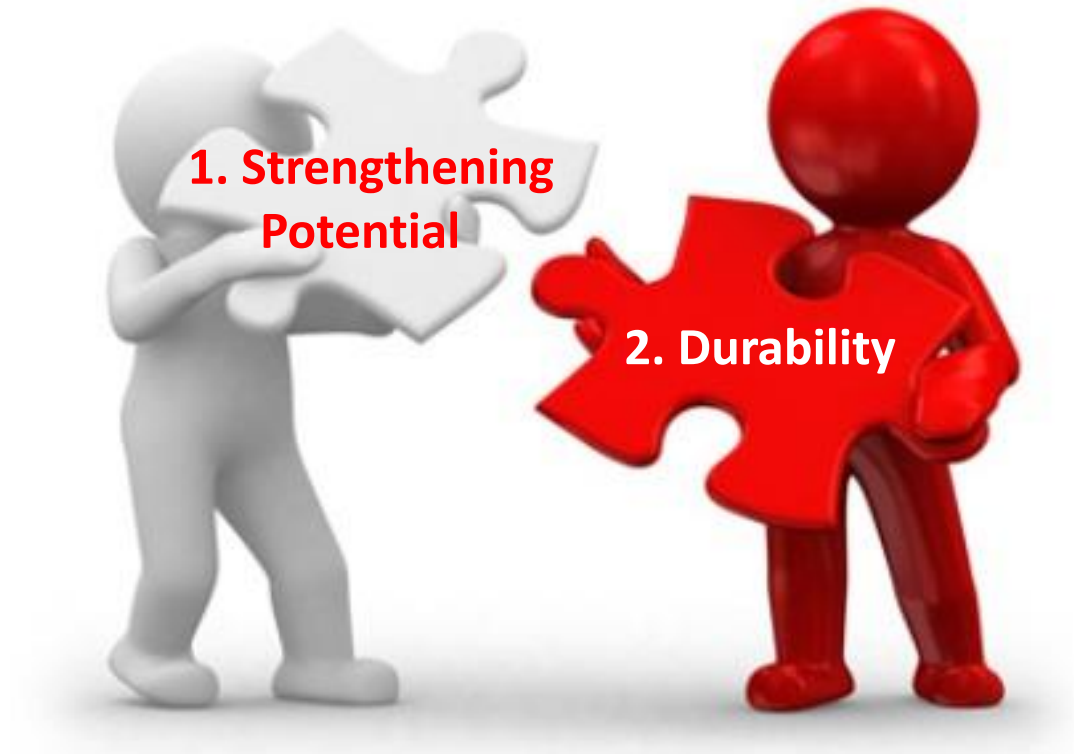
2<sup>nd</sup> International Workshop

20-24 November 2017, Istanbul, Turkey



Characteristic of fibres	Basalt	E-Glass	S-Glass	Carbon
Tensile Strength (MPa)	3000~4840	3100~3800	4020~4650	3500~6000
Elongation at break (mm)	3.1	4.7	5.3	1.5~2.0
Elastic modulus (GPa)	79.3~93.1	72.5~75.5	83~86	230~600
Temperature of use (°C)	-260~+500	-50~+380	-50~+300	-50~+700

## Can Basalt FRP represent an economic alternative to the traditional fibres?

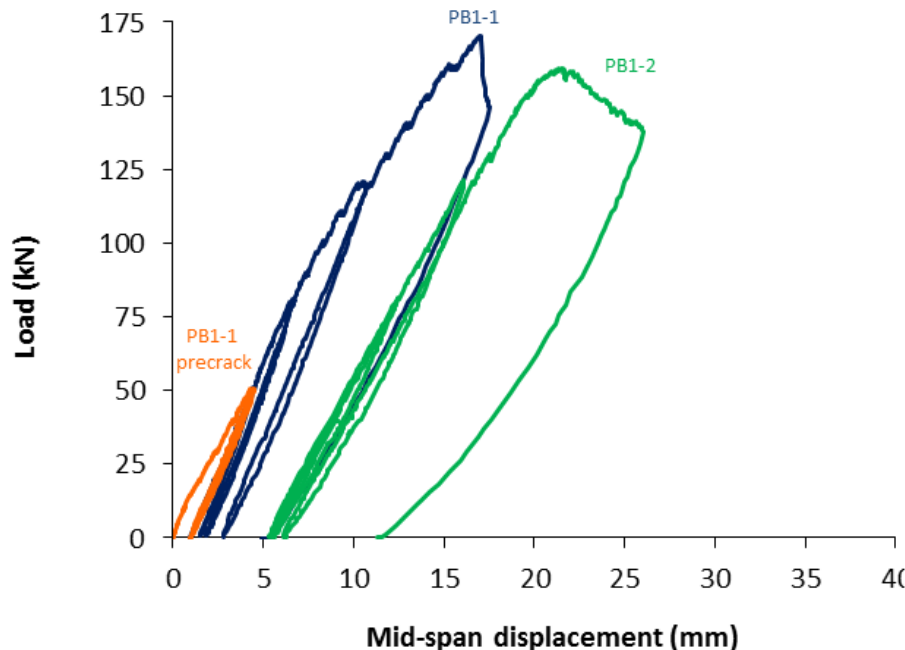


# 1. Strengthening potential of Basalt FRPs

2<sup>nd</sup> International Workshop

20-24 November 2017, Istanbul, Turkey

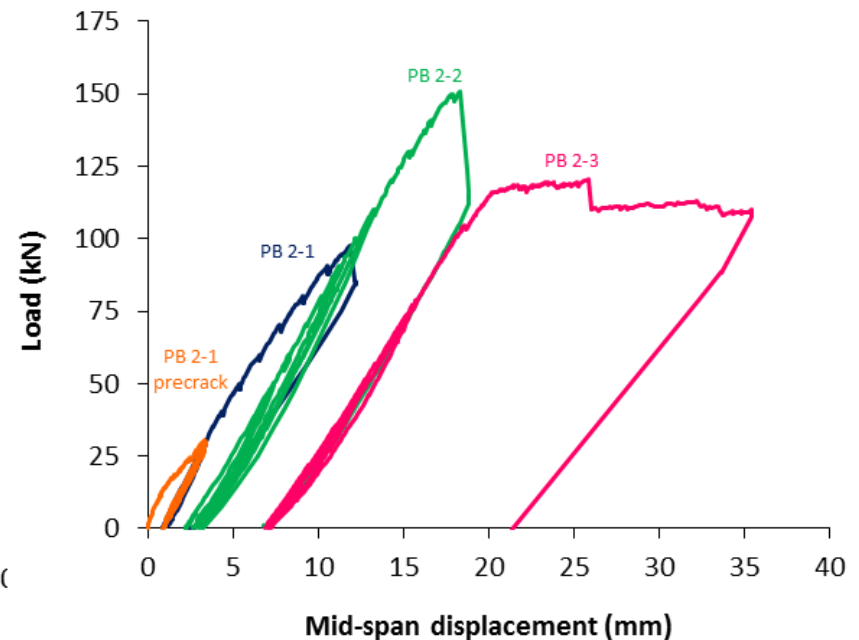
## Experimental Program - Overview



PB1-1 - end debonding

↓  
*added BFRP strips, stronger concrete*

PB1-2 - crushing



PB2-1 – end debonding

↓  
*changed with wider CFRP plate, added BFRP strips, stronger concrete*

PB2-2 – end debonding

↓  
*steel strapped failed side, longer anchorage length*

PB2-3 – end debonding

SB5 – control  
CB0 – control  
*By N. Pesic*

# 1. Strengthening potential of Basalt FRPs

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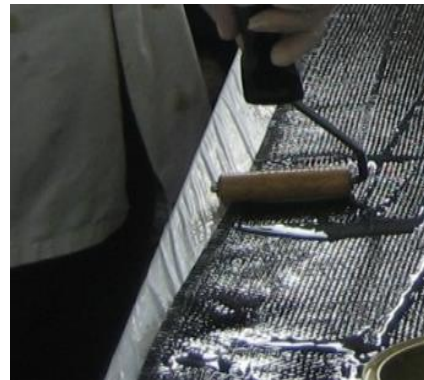
## BFRP strips - preparation



*Basalt fabric*



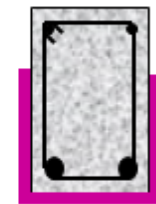
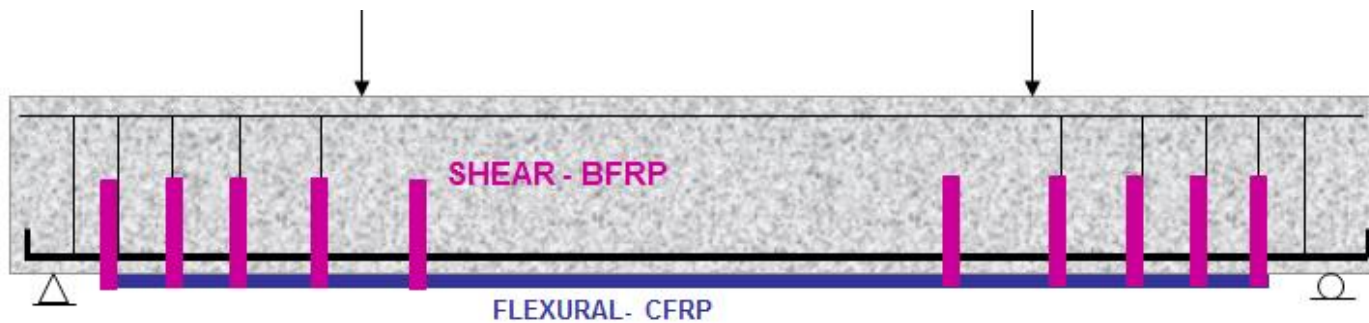
*Basalt strips*



*Impregnate - BFRP*



*Bond onto concrete*



U – strips (235x90) mm

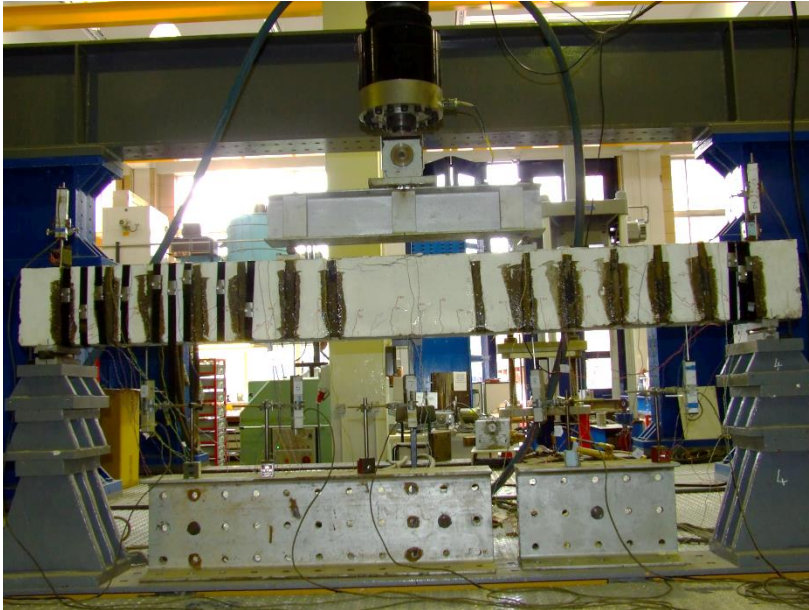


# 1. Strengthening potential of Basalt FRPs

2<sup>nd</sup> International Workshop

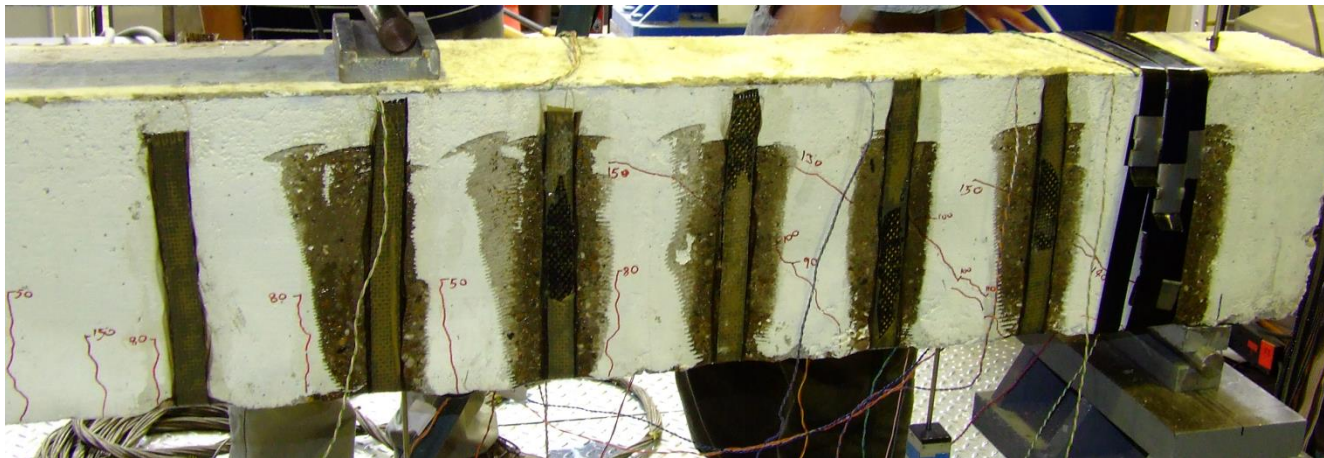
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## Beam tests



Beam	P <sub>ult</sub> (kN)	M <sub>ult</sub> (kNm)	P <sub>y</sub> (kN)	M <sub>y</sub> (kNm)	V <sub>r</sub> (kN)	V (kN)	P <sub>deb</sub> (kN)	Failure mode	P <sub>exp</sub> (kN)
PB1-1	224	86	208	80	20	196	119	End debonding	171
PB1-2	209	80	-	-	20	196	119	Crushing	160
CB0	198	76	196	75	-	150	110	Rip-off	134
SB5	207	79	204	78	34	219	112	Crushing	179

Beam	P <sub>ult</sub> (kN)	M <sub>ult</sub> (kNm)	P <sub>y</sub> (kN)	M <sub>y</sub> (kNm)	V <sub>r</sub> (kN)	V (kN)	P <sub>deb</sub> (kN)	Failure mode	P <sub>exp</sub> (kN)
PB2-1	164	63	120	46	-	398	59	Peel-off	98
PB2-2	216	83	153	59	20	482	97	End debonding	151
PB2-3	206	80	158	60	20	482	62	End debonding	121



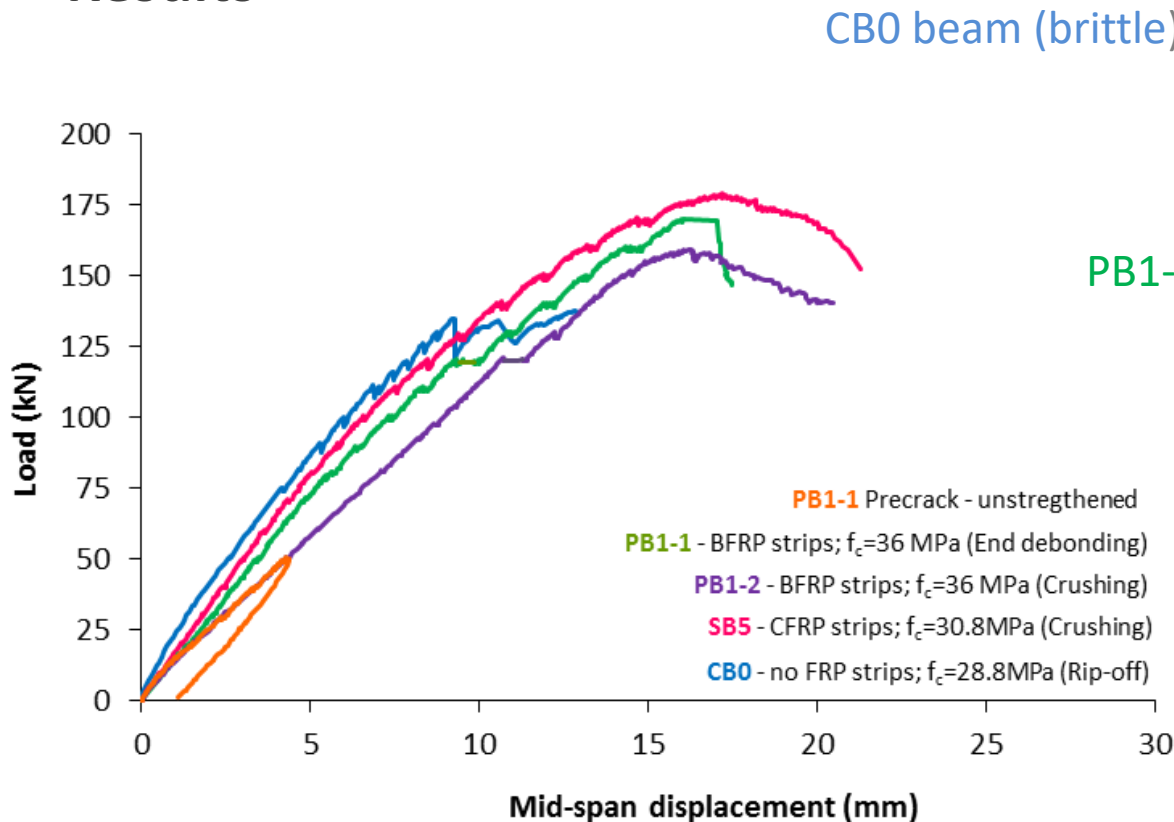


# 1. Strengthening potential of Basalt FRPs

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## Results

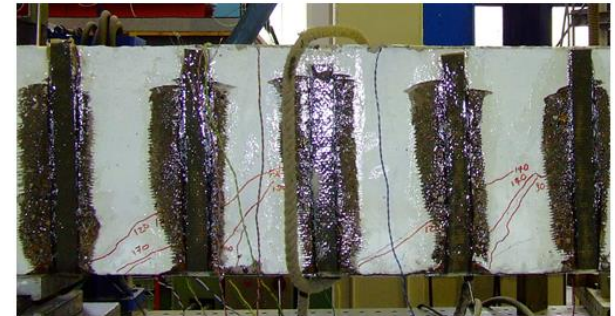


- Increase in debonding load (~27%)
- Pseudo-ductility

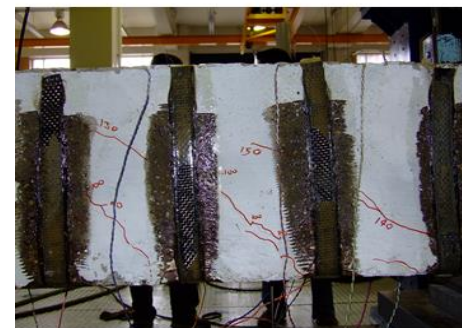
Plate end – crack patterns



PB1-1 beam (distributed cracking)



PB1-1 beam (distributed cracking)



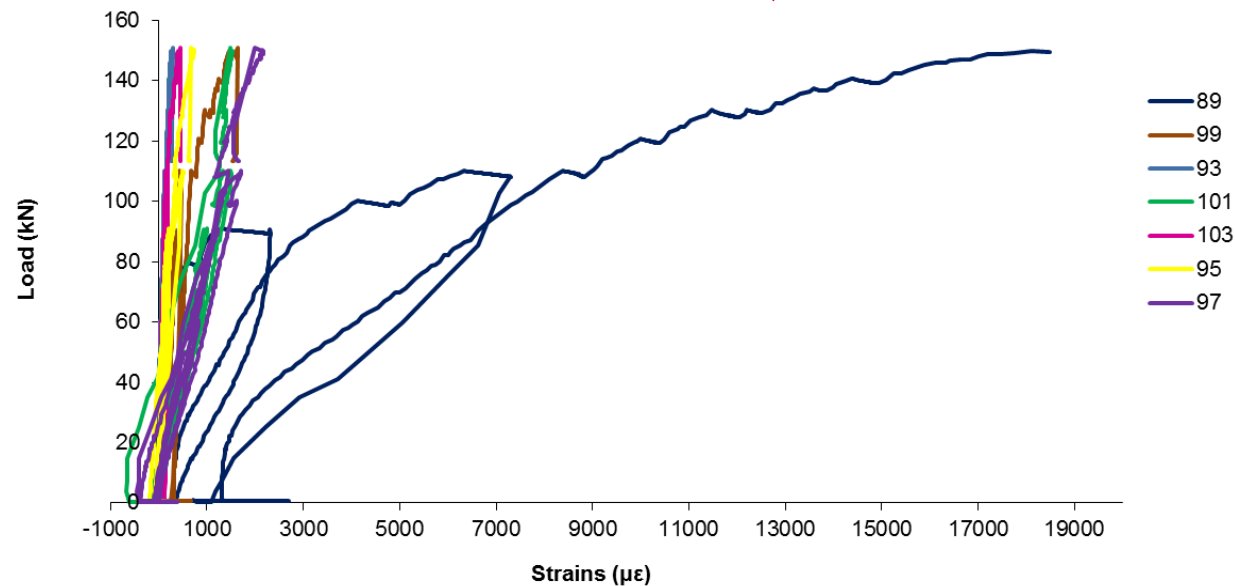
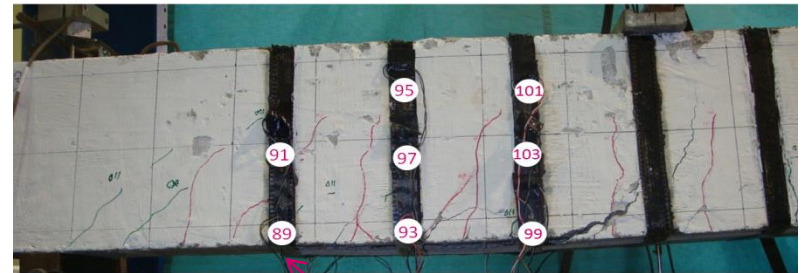
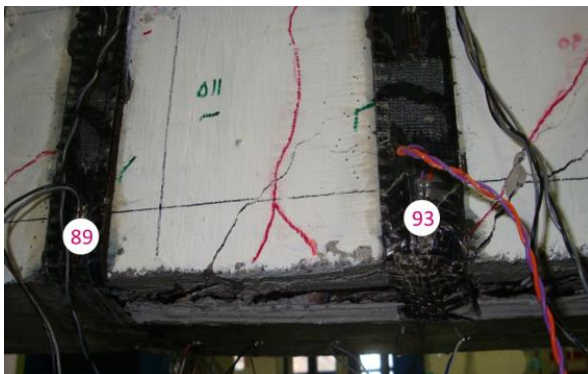
# 1. Strengthening potential of Basalt FRPs

2<sup>nd</sup> International Workshop

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## Results

- High strain in Basalt FRP strips
- No debonding of BFRP strips



## 2. Durability of Basalt FRPs

### Experimental Program - Overview

132 Basalt FRP bars

Set <sup>bar</sup> type	Tests		No. of bars per diameter	Nominal diameter (mm)	Actual area	Total no. of bars
1 <sup>1</sup>	Tensile test (TT1)		5	3	9.6	20
			5	5	23.8	
			5	8	57.1	
			5	10	86.8	
2 <sup>1</sup>	Tensile test (TT2)		5	3	9.4	5
	Durability test (DT2)	Water/20°C/1000h	5	3	9.5	20
		Water/60°C/1000h				
		pH13/20°C/1000h				
		pH 13/60°C/1000h				
	Water/60°C/200h		3	3	9.1	3
3 <sup>2</sup>	Tensile tests (TT3)		9	6	33.3	24
			5	4	15.5	
			5	5	23.6	
			5	7	44.4	
	Durability test (DT3)	pH 9/20°C/100h	5	6	33.2	5
		pH 9/20°C/1000h	5	6	32.9	5
		pH 9/40°C/100h	5	6	33.2	5
		pH 9/40°C/1000h	5	6	30.1	5
		pH 9/60°C/100h	5	4	15.8	20
			5	5	22.9	
			5	6	32.6	
			5	7	44.4	
		pH 9/60°C/1000h	5	6	32.7	5
		pH 9/20°C/5000h	5	6	32.6	5
		pH 9/40°C/5000h	5	6	33.2	5
		pH 9/60°C/5000h	5	6	32.5	5

Note: the nominal diameters were verified and used for stress calculations for bars without strain

- Time:

100h, 200h, 1000h and 5000h

- Alkalinity:

pH7, pH9 and pH13

- Temperature:

20°C, 40°C and 60°C



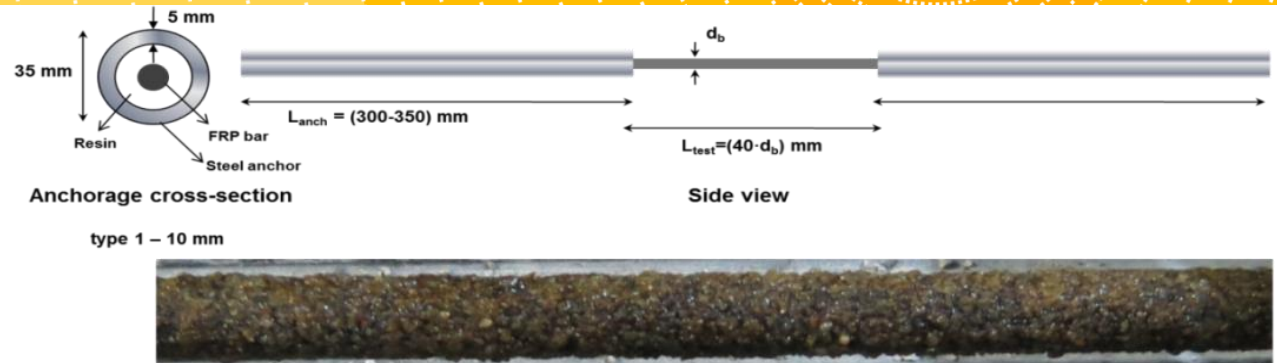
## 2. Durability of Basalt FRPs

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### Conditioning

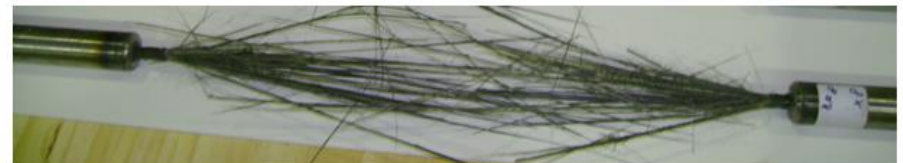
#### Basalt FRP bars



### Conditioning



### Tensile testing



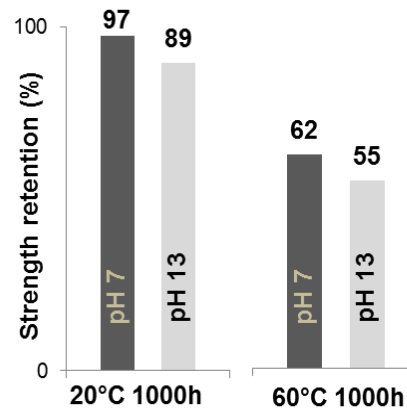
## 2. Durability of Basalt FRPs

### Results

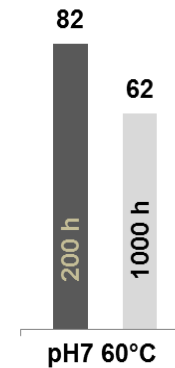
type 1 bars

- pH – less effect
- Temp – high effect

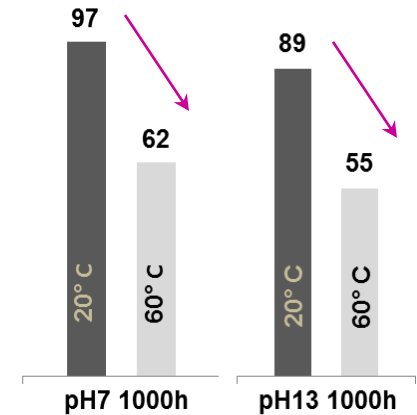
Effect of alkalinity



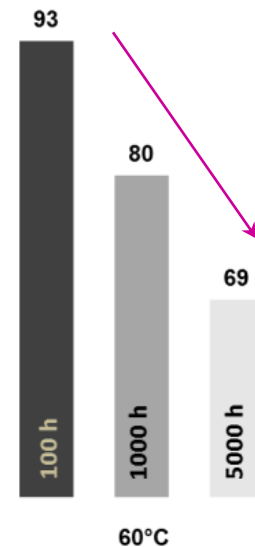
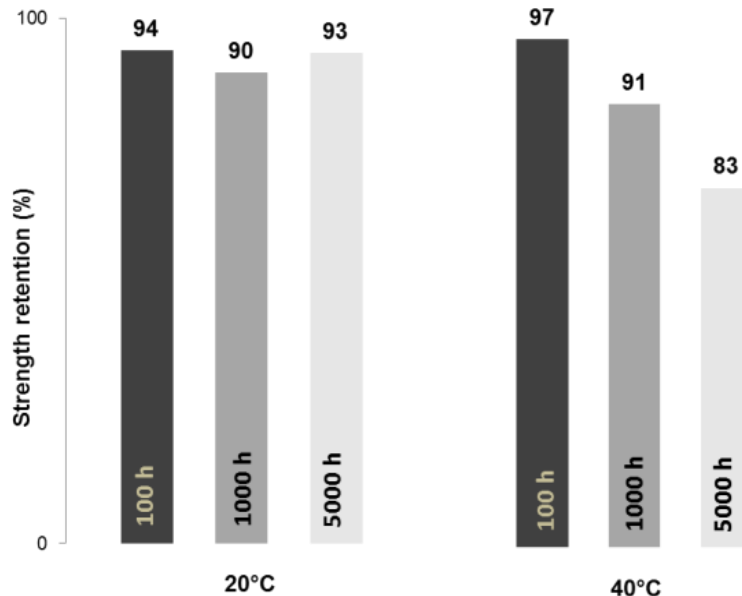
Effect of time



Effect of temperature



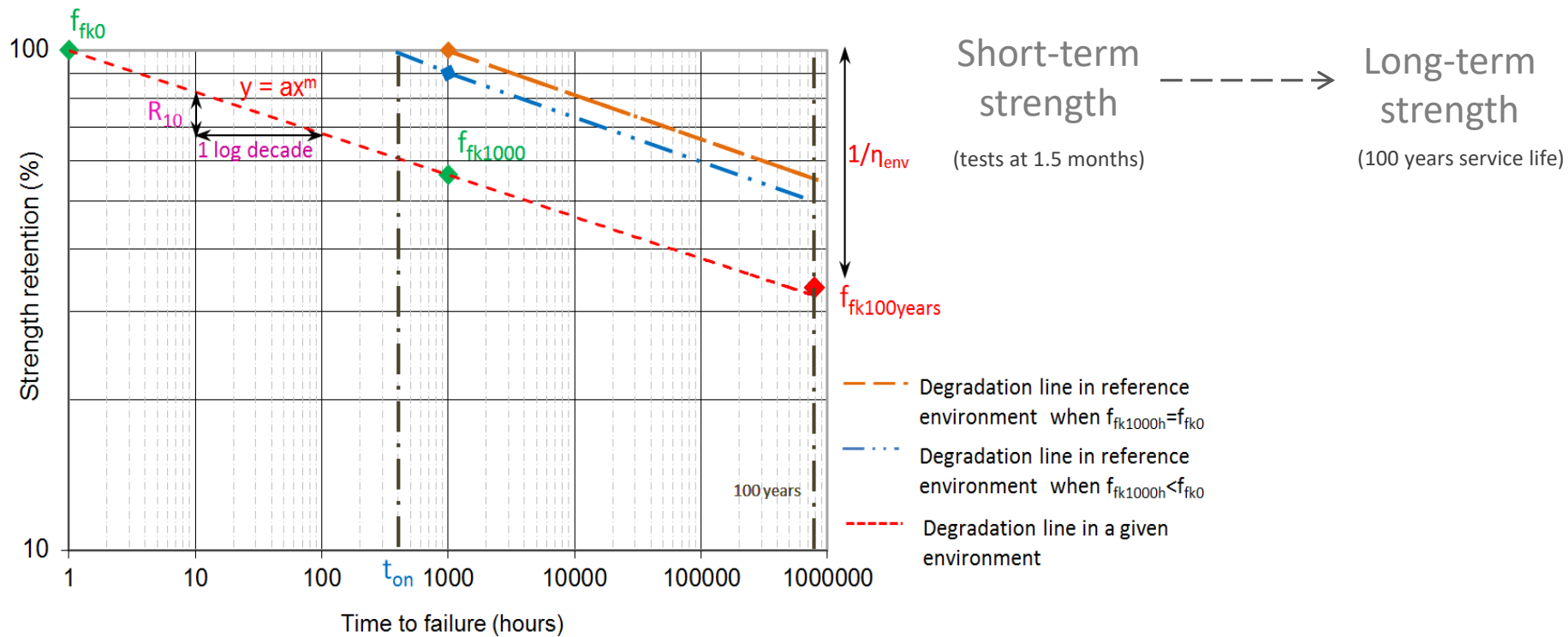
type 2 bars in pH9





## 2. Durability of Basalt FRPs

### Long-term strength prediction in any environment



fib 40 (2007) 
$$n = n_{mo} + n_T + n_t + n_d + n_{pH} + n_{on}$$

$R_{10}$  - cst.

$n_{on}$  - changes

## 2. Durability of Basalt FRPs

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### Long-term strength prediction in any environment

Step 1. Condition specimens

1000h, 20°C, 40°C, 60°C, water, pH13

Step 2. Measure short term-strength

Tensile testing

Step 3. Establish degradation parameters

Use Table

Step 4. Determine the reference degradation curve

Find  $n_{on}$  and  $R_{10}$

Step 5. Estimate the long-term strength

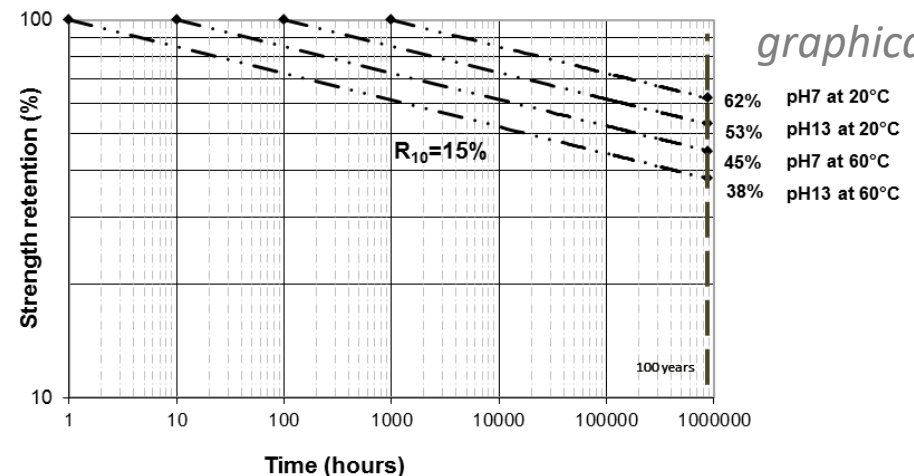
*analytically*

- environmental strength reduction factor

$$\eta_{env,t} = 1 / ((100 - R_{10}) / 100)^n$$

- percentage of the long-term strength retained

$$f_{kt\%} = (1 / \eta_{env,t}) \cdot 100$$



## Strengthening Potential

- 27 % strength enhancement
  - Enabled pseudo-ductile behaviour
- 

## Durability

- BFRP ~ GFRP tensile properties
  - Temp - high effect; pH - less effect
  - 53% strength retention after 100 yrs in concrete
-

Q: Can Basalt FRP represent an economic alternative to the traditional fibres?

A: BFRP – economic solution for concrete when strengthening demand is moderate



# Thank you!



## Acknowledgments

- Magmatech Ltd



Any questions?

